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WHY, WHEN, AND HOW TO MAKE VENTILATION SURVEYS OF METAL MINES [1]

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WHY SURVEYS ARE REQUIRED

Although there is not the same urgent and ever-present necessity for keeping a close check on the ventilation in metal mines that there is in coal mines, yet there are good and valid reasons for having some knowledge of the ventilation conditions in all metal mines. Where hot and humid working conditions are encountered, the value of ventilation surveys and maps for studying ways and means of improving comfort conditions and working efficiencies is recognized to some extent by metal mine operators; but the special value of knowledge of ventilation conditions at the time of mine fire has been recognized, as a rule, after the fire rather than before it. Ventilation is a thing that is for the most part unseen and unobserved, and it is surprising how little accurate knowledge of their ventilation conditions most mine managers and mine foremen have and how many preconceived ideas are upset by a few simple observations.

The most direct application of the information gained by a survey comes at time of mine fire when it is vitally important to have a maximum knowledge of ventilation conditions, especially the direction of air currents. Unless a regular procedure of ascertaining and recording ventilation conditions is followed, the necessary information may not be available for efficient use when and where it is required. Ventilation maps prepared from surveys can also be used to advantage in the preplanning of methods of fire control. Probably the next most important use of such information is in the improvement of present or possible future comfort conditions and working efficiencies. Another important application is in connection with the installation of mechanical ventilation on a mine previously ventilated by natural draft, or in connection with important changes in the airway system in either a naturally or mechanically ventilated mine.

Many metal mines that use mechanical ventilation are surveyed at regular or irregular intervals, but the idea of surveys has not been encountered in any naturally ventilated mines, although a number have been surveyed by engineers of the Bureau of Mines. In naturally ventilated mines, of course, the need is not so urgent, and there is a fixed impression that natural draft is not subject to control. As a matter of fact, whereas natural draft is not subject to a great deal of control, it can often be manipulated so as to obtain greater constancy of direction of air currents and to relieve otherwise distressing conditions.

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BY WHOM SURVEYS SHOULD BE MADE

There is also a fixed impression that ventilation surveys can only be made by experts. If a high degree of absolute accuracy were demanded this would be true, but the essential requirements of such surveys do not demand anything more than the determination of the direction and approximate magnitude of the air currents. Surveys of sufficient exactitude can be made by engineers without previous training, but in order that the information may be properly recorded on the mine maps, it is preferable that such surveys be intrusted to the regular surveying force or, in the absence of a designated mine ventilation engineer, to the safety engineer.

WHEN SURVEYS SHOULD BE MADE

The survey need not be elaborate or require much time. Individual requirements, of course, govern particular mines as to how often surveys should be made. The first requirement is that surveys should be made often enough to keep the mine officials up to date on the essential features of the ventilation of the mine. As a general rule, the minimum number to begin with and to continue until the tidal effect of natural draft is accurately gauged, would be two semi-yearly surveys, taken preferably in mid-winter and mid-summer. For shallow naturally ventilated mines, four surveys a year might be required to give the desired information, whereas for very deep mines yearly surveys eventually will give sufficient data, provided, of course, supplementary data are obtained as to the effect of all major changes in the ventilating system.

HOW SURVEYS SHOULD BE MADE

Information Desired

The main requirements of a survey are to ascertain primarily the direction of flow and the approximate magnitude of the various air currents. Next to the air-flow information, temperature observations - both wet and dry bulb - are most useful. Additional data that are desirable for all mines are rock temperatures in virgin ground and pressures on doors and stoppings. And for mechanically ventilated mines, approximate performance data for all ventilating appliances are desirable matters of record.

Instruments Required

A complete set of instruments required for simple ventilation surveys would cost approximately $85. Average prices for good-grade instruments are about as follows:

Low-speed vane anemometer, with case	$35.00
Sling psychrometer, with case	25.00
Stop-watch one-fifth-second, 30-minute register	15.00
U-tube water gauge, with tubing	5.00
25-foot tape, with case	2.00
Revolution counter	3.00

Use of Smoke Clouds to Determine Minor Air Currents

For determining the direction and velocity of air currents flowing at velocities below about 150 feet per minute, which observations will ordinarily comprise the bulk of the air-flow observations that are made, smoke clouds offer the most readily available and practical means. And the neatest and most convenient method of generating the smoke clouds under mine conditions is to force air through a glass tube (about 1/2 inch outside diameter by 5 inches long)[3] containing pumice stone saturated with fuming sulphuric acid or tin tetrachloride - preferably the latter. The tubes can be sealed at the tips, which are easily broken off at file scratches when ready to use. These tubes give dense white fumes, last from half a shift to a shift, depending on the degree of activity of the observer, and are thrown away when used up. Other methods of smoke-cloud production are, of course, available. Burning fuse is a good method but is less convenient and satisfactory. Aspirated liquids and powders are at best messy, and usually have other disadvantages, especially as to safety and capacity.

To measure velocities by smoke-cloud travel, pace off 25 feet along as straight and uniform an area section as can be found on the airway. Station the smoke-cloud producer at one end of this distance and an observer with a stop watch at the other. The smoke-cloud producer should call the starting time of the cloud production which is made across the airway rather than along it. In slow-moving currents the original cloud can be reinforced by another, or several clouds can be started in different positions in the cross section by producing the succeeding clouds in line with the advancing cloud first produced. The finishing time is arbitrarily taken as that of the passing of the middle of the main body of the cloud or clouds and the clouds are best generated to travel approximately one-seventh of the width or height of the airway from the walls. This distance is the approximate position of the average velocity of flow in straight airways of regular cross section. In irregular airways the distribution of velocities is irregular and the time of travel of clouds started in different positions of the cross section should be averaged. With very low velocity flow in airways where rock and air temperatures differ considerably, there are often large differences between the velocities in the upper and lower parts of the cross section, but these can be roughly averaged from separate cloud-travels. Disturbances due to car, cage, and skip travel in haulageways and shafts should be expected in the vicinity of such activities, and an attempt should be made to secure measurements during normal periods of flow only.

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3 - Katz, S. H. and Bloomfield, J. J., Sulphur Trioxide Smoke Tubes for Determining Air Currents: Reports of Investigations, Serial 2505, Bureau of Mines, July, 1923, 2 pp.

To determine quantities of flow it is of course necessary to know the average area of the cross section of the 25-foot length. In untimbered rock airways areas based on a few measurements will rarely give the area within 10 per cent, but that is close enough. Individual quantities of flow may be in error as much as 30 per cent by these methods, but in general it will be found that where check measurements are possible, a relative agreement within 10 per cent is usually obtained in careful, though rapid, work.

Use of Anemometers for Determining Major Air Currents

For measuring velocities of 150 feet per minute to about 2,500 feet per minute, ordinary commercial types of vane anemometers are most practical and convenient. There is a general impression among engineers that anemometers are unreliable, but it has been the author's experience that anemometers are very reliable if used properly and that the discrepancies often noted are due to other causes than the anemometer, more particularly to the method of use. The accuracy of results is affected to a large extent by the method of use, but not to any greater extent than any other device would be under similar circumstances. And the anemometer has the important advantage that its readings are practically independent of the air density and, for the range encountered in mines, of air temperature. Accurate measurements of air flow can be obtained only by carefully traversing a cross section of a straight air passage of regular area and applying correct calibration factors to observed readings. However, an average accuracy within 5 per cent can be obtained with less refined methods for rapid surveys if calibration and method factors are used and areas are carefully determined.

Anemometer Calibrations

Vane anemometers usually register a velocity that is somewhere within 10 per cent of the true velocity; the latter has to be determined by referring to calibration tests. In this country the U. S. Bureau of Standards, Washington, D. C. is the recognized authority on anemometers and is prepared to calibrate these instruments for a nominal fee. Calibrations are made on a whirling arm with correction for the air swirl set up by the rotation of the apparatus.

Calibrations furnished by the manufacturer with new instruments are usually in the form of tables of plus or minus corrections to be made to observed velocities, and usually agree with Bureau of Standards calibrations within 2 per cent. The latter are issued in the form of a curve in which the factor, by which the observed velocity must be multiplied to give true velocity, is plotted against observed velocity.

It has been found by experiment that the registered velocity is a straight-line function of the true velocity - except possibly for extremely low velocities - of the form $V_T = A + BV_R$; that is, that true velocity (V_T) is equal to a constant (A) plus the product of another constant (B) and the registered velocity (V_R). Apparently, (A) remains constant for any one instrument, is practically the same for all instruments of a general type, and averages about 30 for the ordinary Biram-type low-velocity anemometer. Apparently, also, (B) is practically constant for any one instrument that is kept clean and is not mechanically damaged, and varies but a few per cent between instruments of the same design and make. Between different makes of the same general design, however, variations in (B) of from 0.90 to 1.05 have been found and it appears possible that an instrument could be made with (B) equal to 1.00, in which case it would only be necessary to add the constant (A) to the observed velocity to obtain the true velocity.

If, therefore, anemometer calibrations are plotted with observed velocity against true velocity, a straight line will result, and the method has a number of advantages. First, the straight line will be a "faired-up" average of individual calibration points. Second, the calibration may be based on tests at but two velocities, or, if (A) is known, on one (preferably high) velocity only. Third, the calibration may be reduced to a formula and easily carried around and applied.

Method Factors

For rapid work the anemometer must be used under conditions differing from the conditions under which it was calibrated, and allowances must be made for such differences in order to obtain even approximately correct results. After differences between individual anemometers are eliminated by applying calibration corrections to observed velocities it is necessary to multiply the resulting velocity by a method factor to get the true average velocity for a particular cross section, either to take care of the change of conditions introduced by the measuring operation or to allow for some characteristic of the airflow itself. Important considerations are: Whether average velocities are based on readings at but one point or on a traverse of the section; whether the traverse is made by a precise or by an approximate method; whether the anemometer is mounted on a shaft or held by hand; whether the operator's body does or does not obstruct the air stream; whether the air stream itself has some abnormal characteristic at the place of measurement; and whether the anemometer itself causes an appreciable change in the normal flow condition. Particular methods usually involve a number of these considerations to a varying degree, but it has been found that average method factors can be applied in many cases to give an average accuracy within about 5 per cent.

One-Point Measurements

Probably the simplest and fastest method commonly used is that in which the average velocity is based on a measurement at but one point in the cross section. In straight airways of regular area, with the operator's body out of the air current, such readings give fair approximations directly when made at a point one-seventh of the width or height from the wall, and give good approximations when made at the center and multiplied by 0.80. The latter method is to be preferred, as it is less affected by slight irregularities of the walls, especially in timbered mine airways. However, sufficiently straight and regular airways in mines usually occur only at lined shafts carrying the main intake or return air currents for which it is usually desirable to secure more reliable measurements by careful traversing.

As applied to irregular mine airways, even when the anemometer is mounted on a shaft and the operator is out of the section, this method is decidedly approximate for the reason that, although the average velocity is approximately that occurring at the one-seventh point and approximately 0.80 times the velocity at the center in straight passageways of regular area, these relations vary rather considerably with the conformation of the airways. Even in straight airways, local constrictions and enlargements change the relation of center velocity to mean velocity very considerably - up to 10 per cent for ordinary variations.

The commonly-used method of holding the anemometer at arm's length and at the estimated center of the cross section with the body of the operator completely in the air current, gives especially high readings. In addition to the major variations due to variations in the center-velocity relation to mean velocity, there is also a variable increase in the reading due to obstruction caused by the operator's body. Determined method factors have varied irregularly from 0.65 to 0.90 for 40 to 100 square foot sections of approximately straight airways in rock and in coal, and the method is therefore one that can not be recommended.

Approximate Traverse Methods

In irregular wide airways, where the anemometer can not be operated from a position out of the air current, results within about 5 per cent can be obtained by making a continuous slow traverse on vertical lines, with the operator in the plane traversed and moving slowly across it with the instrument held by hand at arm's length in front of him, and using a method factor of 0.90.

For similar conditions, but with the traverse started with the operator's body out of the current - in a recess or back of a timber or doorframe, - a method factor of 0.85 can be used. For narrow airways the same factor of 0.85 can be used where the operator stands near the middle and traverses both halves from positions to one side of the center.

In lined airways it is possible to traverse the section from a point behind the lining with the instrument mounted on a short shaft. At a tight timber set, a method factor of about 1.02 is required, but often there is some flow back of the timbers and a general factor of about 0.95 for lagged timbered airways will more generally give approximate results.

Doorframes, with regular areas 40 to 60 per cent of the airway areas, are of frequent occurrence on irregular metal-mine airways and are often better places for air measurements than the airway sections. For wide doorframes, with the anemometer held at the center at arm's length, use a method factor of 0.80. For narrow doorframes, with the body back of the frame, use 0.85. If the anemometer is mounted on a shaft and placed at the center with the operator back of the frame, use 0.90. For a continuous traverse of a narrow doorframe by hand from one side, use 0.90, but if the traverse is made from both sides, with only the operator's arm in the section, use 0.95. For a continuous traverse with an anemometer mounted on a shaft and operated from back of the frame, use 0.98.

In all continuous traversing it is desirable to regulate roughly the speed of traversing so that equal parts of the cross section are covered in equal intervals of time; it is often desirable to have and assistant call out 5 or 10 second time-intervals. Any regulation of speed to time should be done while the anemometer is about one-seventh of the width or height from one wall. Exact results depend on how carefully the traversing is done, but with a little practice in obtaining slow steady movement it is generally found that a relative agreement within about 2 per cent is obtained in check measurements under almost any conditions; as an extreme illustration of this point, this degree of relative agreement was obtained in duplicate traverses of arched tunnel sections 27 feet wide and 20 feet high with an anemometer mounted on a 14-foot shaft and operated from the top of a 12-foot stepladder.

The fact that an obstruction, such as the operator's body, changes the normal velocity distribution for a considerable distance upstream is rarely recognized. To take a special case, anemometers are sometimes operated on the end of a 4 to 6 foot shaft by an observer standing some distance downstream from the anemometer position. Readings taken in this way will give low results, probably to the extent of 5 to 10 per cent. Then again, where separate readings are taken at each of a number of properly arranged traverse points, the starting and stopping of the anemometer, unless some method of remote control is used, requires the operator to obstruct the air current twice for each reading, which will have some effect on the accuracy of the readings.

Precise Traversing Methods

Precise traversing is only justifiable on major air currents or in connection with tests on fan performance to determine the pressure-volume relations; and it should only be applied at sections of fairly regular area on straight airways. Traverse points should be located - by strings, wires, or marks on guide frames - at the centers of approximately equal areas of the cross section. Their number should depend on the shape of the section and should vary from not less than 16 for a square section to not less than 24 for a section in which one dimension is twice the other. Methods that involve the intermittent or continuous obstruction of the air current, either upstream or downstream, do not give precise results and may be very inaccurate. Precise traversing is most practically and conveniently carried out by mounting the anemometer on a shaft and traversing the section by what might be termed continuous point-traversing from a position entirely out of the air current. In this method the anemometer is not started and stopped at each traverse position, but is started at the first position, is slowly moved to a new position at the end of each 10, 20, or 30 second period, and is stopped at the last position, the traverse points being arranged so that the start and stop positions are on the same side; or the traverse points may be covered twice to bring the stop position at the same point as the start position. Narrow airways, up to 5 feet in width, can be covered from one side with a 30-inch shaft, with but little interference from the operator's arm. Airways up to 10 feet in width can be covered in halves, one-half from each side, and, where conditions permit, narrow airways can be covered similarly with possibly a slight gain in accuracy. For airways wider than 10 feet, it is desirable to stretch wires across the airway and use a hook attachment to suspend the anemometer which is placed as to position laterally by means of a shaft, as before, either from one or both sides. Pulley and guide arrangements have also been used for traversing wide airways and, more particularly, for very high airways.

In general, results accurate to within 2 per cent can be obtained with precise traversing at good sections without the use of method factors and disregarding the effect of air density. Precise traversing is sometimes carried out at doorframes that constrict the area of the airway roughly about 50 per cent, in which case it is necessary to use a method factor of 0.95. With anemometer shafts operated on a carefully constructed guide frame, relative agreement to 0.1 per cent can be obtained and absolute accuracy better than 2 per cent can be secured under the best of conditions.

The effect of air density on calibrations, according to Ower[4] is negligible at or near sea level and, except for very low velocities, is practically negligible for large density differences. If $\underline{d}$ is the density where the reading is made and $\underline{d_s}$ the density at which the calibration is made, the constant (A) in the calibration equation should be changed to $A\sqrt{\frac{d_s}{d}}$ to allow for the air-density effect. For the ordinary low-velocity vane anemometer this requires the addition of but approximately 3 f.p.m. to corrected velocities for points 5,000 feet above sea level.

Accuracy of Mine Air-Flow Measurements

Good relative agreement is, of course, not the same thing as absolute accuracy. In general, rough measurements of velocities and areas for minor air distribution will give flow measurements with an average accuracy of about 10 per cent; whereas careful anemometric measurements of velocity and careful estimates of areas on the major air courses will give flow measurements with an average accuracy of about 5 per cent. Considering the variations in air quantities that normally occur in mines due to changing natural-draft conditions and the effect of many other variables, these degrees of accuracy are sufficiently precise for ordinary practical purposes. However, in determining fan performance for a particular purpose, more accurate flow measurements are often desirable, and an accuracy within 2 per cent can be obtained by close attention to details. Under mine conditions it is rarely possible to obtain accuracy under 2 per cent, even with other methods of air measurement, and such accuracy calls for specially skilled technique that is hardly warranted except for purposes of research.

Considering the inaccuracies of most mine air-flow measurements, the practice of reporting quantities to the last cubic foot per minute is unwarranted. It is suggested that quantities below 10,000 c.f.m. be reported

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4 - Ower, E., Measurement of Air Flow. London, 1927.

to the nearest 500 c.f.m., and that above 10,000, even thousands be considered sufficiently precise.

In considering the relative agreement of the quantities of flow in cubic feet per minute as measured in various parts of a mine, the effect of compressed air liberated in the workings and of changes in air density on quantities of flow should be taken into account, since either one may account for rather large differences in flow measurements.

Air-Temperature Observations

By air temperature is customarily meant only the dry-bulb temperature of the air as determined by the ordinary thermometer. But to express the condition of the atmosphere properly, another temperature - the wet-bulb temperature - is also required. This is obtained by the ordinary thermometer when a wet cloth sack is placed over the mercury bulb and the latter is exposed to a current of air. The evaporation of moisture from the sack cools the bulb of the thermometer a certain amount, determined by the water-vapor content of the air, and the temperature thus obtained is termed the wet-bulb temperature. Relative humidity can be determined by U. S. Weather Bureau tables[5] from the wet and dry bulb temperature if it is desired, but it is suggested that for mine ventilation surveys the direct record of wet and dry bulb temperatures is more significant. The wet-bulb temperature is a direct measure of the total heat in the air and also designates the temperature the air will take upon saturation with moisture without any change in heat content.

Thermometers with the scale etched on the glass are preferred, since a 10-inch thermometer graduated from about -20 degrees to +130 degrees can usually be relied upon to be accurate within 0.2 degrees F. For convenience, two thermometers are mounted on a frame equipped with a pivoted handle and the assembly is termed a psychrometer. The required air movement over the wet bulb is provided by whirling the psychrometer. The wet-bulb reading should be made as soon as the instrument is brought to rest. Consecutive readings are necessary until the minimum temperature is determined.

Except in the upper 500 to 1,000 feet of downcast shafts, mine air temperatures change very slowly; readings at 500 to 1,000 foot intervals in shafts and at 1,000 to 2,000 foot intervals on working levels, combined with readings at the face of every third or fourth working place, give a sufficient indication of air-temperature conditions throughout the mine, although additional readings will often be desired to establish the effect of some local condition.

Rock-Temperature Observations

The temperature of the rock strata has been found to increase with increase in depth below the surface, but the rate of increase is not constant everywhere, varying from about 1 degree F. for every 60-foot increase in depth

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5 - Marvin, C. F., Psychrometric Tables: U. S. Department of Agriculture, W. B. No. 235, 1915, 84 pp.

to 1 degree F. for every 250-foot increase. At every deep mine, therefore, the subject of the increase in temperature of the virgin rock is of interest. Air currents, however, change the temperature of the rock along airways to a considerable depth. Rock temperatures, to be of any value, should be taken in dry holes in the faces of advancing headings where the air temperature is practically the same as the rock temperature. Good rock temperatures can often be obtained simply by taking the air temperature at the faces of long unventilated dead ends extending into virgin country, but the heating effect of men in a confined space must be avoided by prompt one-man observations.

Pressures on Doors and Stoppings

Occasional measurements of the pressure difference between the two sides of a door or stopping are matters of interest in either naturally or mechanically ventilated mines. No great accuracy is required and the readings can be made with a simple U-tube. A convenient homemade instrument for underground use can be constructed by mounting a 5-inch U-tube made of 1/4-inch O.D. glass tubing, with the legs on about 1-inch centers, on one-half of a piece of white cardboard on which a black-line scale of inches and tenths has been ruled. The tube can be secured by small rubber bands, and protected by folding the other half of the card over and securing it by another rubber band. The scale should preferably be protected from dirt by a piece of celluloid held in place by mounting tissue of some sort. A short length of 1/8-inch I.D. rubber tubing - say 2 to 3 feet long - is attached to one leg of the U-tube. In use the tube is held against the scale, and the card is held against a side of the door or stopping while the tube is pushed through a hole or crack to the other side. With the tube vertical, the difference in level of the two liquid-levels is read. The flexible mounting makes it possible to bring one level to an even division of the scale. The only additional precaution required is to see that both openings are in quiet air and especially that neither one is opposite a crack or hole where a high velocity of flow might exist. It is also desirable to arrange the reading to come about at the height of the eye.

Fan Performance Data

In mechanically ventilated mines there are usually three types of installations: Primary, secondary, and auxiliary. The first provides the major circulation and handles the total quantity of flow. The second type is more often termed "booster" installation, in that it boosts the pressure of part of the flow. The third type merely circulates a small part of the flow from the primary circulation to and from dead-ended working places. The desired accuracy of test data is in about the order given. High accuracy is desirable for performance tests of primary units - say with 2 per cent. For booster installations an accuracy within 5 per cent is usually all that is desired or conveniently attained, and for auxiliary installations an accuracy within 10 per cent is ordinarily satisfactory and about all that is easily attained.

For an auxiliary unit it is desirable, in a survey, to determine only the quantity of flow at the end of a fan-pipe line. It is suggested that for rigid pipes the reading be taken by holding an anemometer, mounted on a short shaft, at the center of the pipe end and applying a method factor of 0.85 for a discharge end or of 0.70 for an inlet end. With canvas pipe on blower lines, the end condition is such that only very approximate measurements can be made, and it is suggested that the reading be taken by holding an anemometer by hand at the center of the discharge and applying a method factor of 0.80.

Approximate performance of secondary, or booster, fan installations, usually involves only speed, quantity, and pressure measurements. Speeds are determined with a revolution counter. Quantity measurements have been discussed. The most convenient pressure to measure is the difference of pressure on the two sides of the stopping at the fan, which is a differential static pressure roughly equivalent to the static pressure rating of the fan. More precise methods can be used, but since they involve additional instruments and calculated pressure corrections they are beyond the range of the type of survey discussed here.

Approximate determinations of performance of primary fan installations should include precise methods of measuring the speed and the flow and an approximate determination of the difference in static pressure between the fan housing and the atmosphere. Accurate determinations of fan pressures and their correlation to fan ratings require additional instruments and calculated pressure corrections, and are beyond the range of the type of survey under discussion.

When changes in ventilation systems are contemplated, and for purposes of record, it is desirable to have a measure of the horsepower consumed by fans; but this information, assuming that the fans are electrically driven, should be determined by the electrical department. In connection with fan installations it should be remembered that ratings are based on a standard sea-level air density, or weight of air, of about 0.075 pound per cubic foot. Quantities of flow are independent of the air density, but pressures and powers vary directly with it.

RECORDS

The original records of a survey should be systematic and complete and should be preserved for future reference, since much of the detail is such that it can not be presented in map form.

In order that the data gathered in a survey may be used to best advantage, it is necessary that it be entered on prints of the mine maps with the use of a definite series of symbols. Where the workings are on or along a single vein or other simple layout, this is all that is required to put the data in shape for ready reference. Where the workings are so extensive and so complicated that no single map is in use for engineering purposes, it is often possible to make a diagrammatic plan or elevation on which to show the ventilation data in a way that makes it readily accessible. Unless the main data as to quantity and direction of flow can be placed on a single drawing, the survey does not serve its most useful purpose of presenting at a glance the essentials of the ventilation of the mine. For complex layouts, an isometric drawing, with or without some distortion for the sake of clearness, should be worked up for the mine, and the essentials of the ventilation data should be entered on prints of the same. Such a type of drawing serves especially well for mines having workings on inclined veins pierced by vertical shafts connected by crosscuts to the workings.

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